THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

Research Triangle Institute

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**NO_x AIR POLLUTION CONTROL TECHNOLOGY**		
APPLICATION:	**A PROCESS-INHERENT NO_x EMISSION CONTROL SYSTEM FOR GAS TURBINE APPLICATIONS**		
TECHNOLOGY NAME:	**XONON™ COOL COMBUSTION**		
COMPANY:	**CATALYTICA ENERGY SYSTEMS, INC.***		
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The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by substantially accelerating the acceptance and use of improved and cost-effective technologies. ETV seeks to achieve this goal by providing high-quality, peer-reviewed data on technology performance to those involved in the design, distribution, financing, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations; with stakeholder groups that consist of buyers, vendor organizations, permitters, and other interested parties; and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

The Air Pollution Control Technology (APCT) program, one of 12 technology areas under ETV, is operated by the Research Triangle Institute (RTI) in cooperation with EPA's National Risk Management Research Laboratory. Midwest Research Institute, on behalf of the APCT program, has evaluated the performance of a nitrogen oxides (NO_x) control technology utilizing flameless catalytic combustion for stationary gas turbines, Xonon™ Cool Combustion (formally known as Xonon™ flameless combustion.)

VERIFICATION TEST DESCRIPTION

All tests were performed in accordance with general guidance given by the APCT program "Generic Verification Protocol for NO_x Control Technologies for Stationary Combustion Sources" and the specific technology test plan "Verification Test/QA Plan for Xonon™ flameless combustion system." These documents include requirements for quality management, quality assurance, auditing of the test laboratories, and test reporting format.

The Xonon™ Cool Combustion system was tested as installed and operating on a Kawasaki M1A-13A gas-turbine-generator set (1.5 MW) located in Santa Clara, California, on July 18 and 19, 2000. NO_x concentrations were measured using continuous emission monitors (CEMs) following EPA Reference Method 20 for gas turbines. Other gaseous emissions were monitored using the applicable EPA test method. Other process variables were monitored using calibrated plant instrumentation.

Tests were conducted to meet the data quality objective of a 95 percent confidence interval with a width of ±10 percent or less of the mean NO_x emission concentration for concentrations above 5 ppmvd, ±25 percent or less below 5 ppmvd and above 2 ppmvd, and ±50 percent or less below 2 ppmvd. In addition to outlet NO_x concentration and the primary process variables, carbon monoxide and unburned hydrocarbon emission concentrations were also measured using EPA reference methods, and the installation efforts, site modifications, staffing, maintenance requirements, and similar issues were noted qualitatively.

A single test run consisted of measuring outlet NO_x concentration and the other parameters over a 32-min steady-state process condition with the primary variable, ambient temperature, at either its low point or high point (i.e., early morning or late afternoon). The test design was a replicated 2 × 1 factorial using two levels of ambient temperature and greater than 97 percent of the rated full load. A total of 12 test runs were conducted over the 2-day field test period. Ambient temperature variation was small over the test period. Table 1 gives the operating performance envelope over which the Xonon™ Cool Combustion system was verified.

Verification Statement Table 1. Verification Test Performance Envelope[a]

	Ambient Temperature, °C
Low	15
High	25

[a]At >97 percent of full turbine load.

DESCRIPTION OF XONON™ TECHNOLOGY

This verification statement is applicable to the Xonon™ Cool Combustion system for gas turbine applications without the air management system. The Xonon™ Cool Combustion system is completely contained within the combustion chamber of the gas turbine. Xonon™ Cool Combustion completely combusts fuel to produce a high-temperature mixture, typically about 1300 °C (2400°F). Dilution air is added to shape the temperature profile required at the turbine inlet.

The Xonon™ Cool Combustion system consists of four sections:

- **Preburner.** The preburner is used to preheat the air before it enters the catalyst module and during startup for acceleration of the turbine. The preburner tested as part of this verification was a lean, premixed combustor.
- **Fuel injection and fuel/air mixing system.** This unit injects the fuel and mixes it with the main air flow to provide a very well mixed, uniform fuel/air mixture to the catalyst.
- **Xonon™ catalyst module.** In the catalyst module, a portion of the fuel is combusted without a flame to produce a high-temperature gas.
- **Homogeneous combustion region.** Located immediately downstream of the catalyst module, the homogeneous combustion region is where the remainder of the fuel is combusted, and carbon monoxide and unburned hydrocarbons are reduced to very low levels (also a flameless combustion process).

The overall combustion process in the Xonon™ system is a partial combustion of fuel in the catalyst module followed by complete combustion downstream of the catalyst in the burnout zone. Partial combustion within the catalyst produces no NO_x. Homogeneous combustion downstream of the catalyst usually produces no NO_x, because combustion occurs at a uniformly low temperature. A small amount of fuel is combusted in the preburner to raise the compressed air temperature to about 470°C (880°F). NO_x in the turbine exhaust is usually from the preburner.

The design of each Xonon™ combustor is customized to the particular turbine model and operating conditions of the application and would typically be defined through a collaborative effort with the manufacturer of the turbine to integrate the hardware into the design. Catalytica Energy Systems, Inc. expects that the Xonon™ Cool Combustion technology incorporated in a Xonon™ combustion system for a natural-gas-fueled Kawasaki M1A-13A gas turbine is capable of achieving emissions of NO_x of less than 2.5 ppmvd (corrected to 15 percent oxygen [O_2]) on a 1-hour rolling average basis, and less than 2.0 ppmvd (corrected to 15 percent O_2) on a 3-hour rolling average basis. Under the same conditions, the Xonon™ combustion system is expected to achieve carbon monoxide (CO) emissions of less than 6 ppmvd (corrected to 15 percent O_2). The footprint may vary depending on the implementation, although generically the Xonon™ combustion system would likely be somewhat larger than the combustor that is typically supplied as standard equipment by the turbine manufacturer. Each unit could have multiple fuel inputs from separate control valves, and additional instrumentation for control and monitoring would be integrated into the turbine control system.

This verification statement covers application of the Xonon™ Cool Combustion system to small gas turbines operated at full load when combusting natural gas within the stated operating condition envelope. This unit was operated at the test site by the vendor, Catalytica Energy Systems, Inc., for over 4,000 hours before the verification test. Data from this long-term operating period have been submitted to a number of regulatory authorities for their review and evaluation. While these data and the instruments used were not verified during this test, within the operating condition envelope the results are generally consistent with the verification test results. Catalytica Energy Systems, Inc. should be contacted for these data or other information.

VERIFICATION OF PERFORMANCE

The verified NO_x emission results are given in Table 2. The analysis of variance between NO_x and ambient temperature indicated that ambient temperature did not affect NO_x emissions over the narrow range encountered during this verification test.

Verification Statement Table 2. NO_x Control Performance

Ambient Temperature Range	Percent of Full Turbine Load Range	Mean Outlet NO_x Concentration ppmvd @ 15% O_2	Half-Width of 95% Confidence Interval on Mean Outlet NO_x ppmvd @ 15% O_2
15 to 25°C (59 to 77°F)	98-99%	1.13	0.026

ppmvd = parts per million by volume dry basis.

CO emissions averaged 1.36 ppmvd at 15 percent O_2. Unburned hydrocarbon (UHC) emissions averaged 0.16 ppmv (wet basis reported as propane).

The APCT quality assurance (QA) Officer has reviewed the test results and quality control data and has concluded that data quality objectives given in the NO_x Control Technology generic verification protocol and test/QA plan have been attained. During the verification tests, the EPA and APCT QA staffs conducted a performance evaluation and a technical system audit at the field test site, which confirm that the verification test was conducted in accordance with the EPA-approved test/QA plan.

This verification statement verifies the NO_x emissions characteristics of the Xonon™ Cool Combustion system within the range of application tested (see Table 2). Extrapolation outside that range should be done with an understanding of the scientific principles that control the performance of the Xonon™ Cool Combustion system. Gas turbine users with NO_x control requirements should also consider other performance parameters such as service life and cost when selecting a NO_x control system.

In accordance with the NO_x Control Technology generic verification protocol, this verification report is valid indefinitely for application of the Xonon™ Cool Combustion system within the range of applicability of the statement.

Original signed by Hugh W. McKinnon 12/15/00
Hugh W. McKinnon — Date
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National Risk Management Research Laboratory
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Original signed by Jack R. Farmer 12/22/00
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